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Influence of Spin Rate on Side Force of an Axisymmetric Body

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Introduction

THE study of the side force on bodies of revolution at high angles of attack and zero sideslip has received considerable attention in recent years.[1-3] On foreboides it has been found that the side force can be as much as 1.5 times the normal force.[1] In some investigations, the model was tested at several fixed angles of roll, and it was found that in some positions a side force was produced which was opposite in sign and nearly equal in magnitude to that found in other positions. In addition, a model with a removable portion of the tip was tested with the tip at several fixed angles of roll, and changes in the side-force direction were obtained which were similar to the changes when the complete model was rotated. Other investigations have spun models about their axes of symmetry and observed the variation in side force.[3] The results given herein are from an investigation in which a cone was spun at several rates about its axis of symmetry, and the resulting side force was recorded on an oscillograph. The results are compared to determine the influence of spin rate on side force.

Experiment and Discussion

The model used in this investigation was a 10-deg half-angle pointed cone, 57.9 cm in length. The cone was made of magnesium, for lightness and to minimize inertial effects, and was machined internally to house a six-component strain gage balance and an electric motor to rotate the cone about its longitudinal axis. Tests were conducted in the 6-×6-ft transonic/supersonic wind tunnel and the 12-ft pressure wind tunnel at Ames Research Center at a Mach number of 0.6 and a Reynolds number R_d of 1×10^6 (based on diameter). Static tests were conducted at various fixed roll angles and angles of attack. Spin tests then were conducted at angles of attack of 42.5-45 deg and of 58-60 deg. Because they demonstrate better the changes in side force direction with roll, only the data taken at angles of attack of 58-60 deg are presented.

The model was spun in both directions, and oscillograph traces of the signal from the balance were recorded. A calibration of the dynamic response of the balance used was not made; however, these Task balances are known to have a natural frequency above 1 kHz, which is far above those frequencies experienced during the test. The dynamic balance of the model was checked at zero air velocity and at the angles of attack and spin rates at which data were taken. No model imbalance could be detected in the oscillograph traces. The model roll position Φ was measured from a vertical axis, in a counterclockwise direction looking forward, to an arbitrarily established radial line on the model. Curves were hand-faired through the noise so as to produce smooth traces and yet maintain the basic form of the curves as much as possible. Most of the data presented are for counterclockwise rotation.

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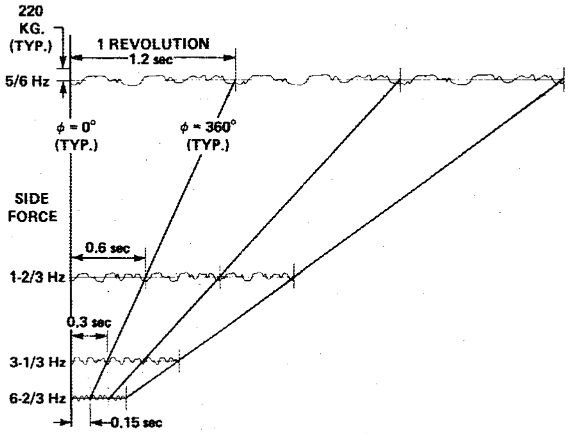

Fig. 1 Typical oscillograph traces of aft side-force gage of six-component balance.

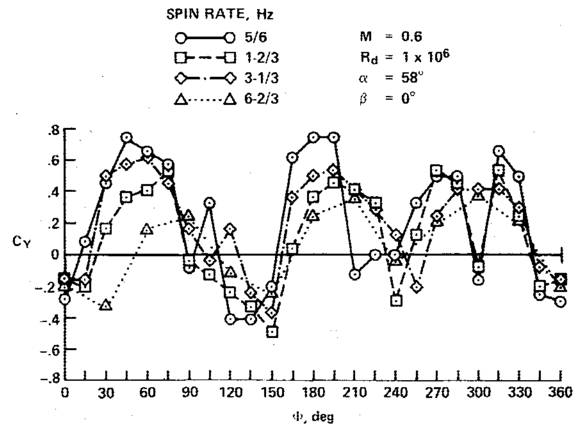

Fig. 2 Side-force coefficient vs roll position.

The resulting traces from the aft side-force gage are shown in Fig. 1. Three revolutions at each spin rate are shown. The side force changes direction in an irregular manner within a cycle; however, this irregular pattern was repeatable from cycle to cycle. The change in direction of side force is thought to be the result of a changing vortex pattern over the model caused by asymmetries in the model geometry, especially near the tip. As the spin rate is increased, it is seen that the general shape of the trace is maintained, whereas the smaller excursions tend to disappear. The signal traces from the forward side-force gage showed similar characteristics, but the magnitude was much less.

Presented in Fig. 2 is the variation of the side-force coefficient with roll position Φ at several spin rates. The total side force was obtained by adding the measured side forces from the forward and aft side-force gages. The side force is seen to experience roughly three cycles during one revolution of the model. This cyclic variation of side force could be attributed to the physical shape of asymmetries in the model tip and to the manner in which the resulting flow is influenced by spin rate. However, the basic shape of the side-force curve is not a strong function of spin rate. There is some evidence that the cyclic variation of side force at the higher spin rates lags that

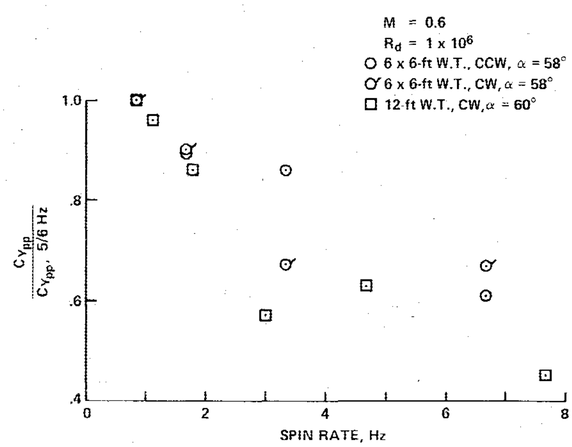

Fig. 3 Peak-to-peak side-force coefficient vs spin rate.

at lower spin rates, but the scatter in the data makes a firm conclusion difficult. There is strong evidence that the amplitude of the side force decreases with spin rate.

The peak-to-peak (maximum negative to maximum positive) side-force coefficient $C_{y_{pp}}$ was taken from Fig. 2 for each spin rate, normalized by the value at 5/6 Hz, and plotted vs spin rate in Fig. 3. Also shown in Fig. 3 are data for a test with clockwise spin and from the 12-ft pressure wind tunnel. As the spin rate is increased, a definite decrease in side force is seen in all of the data. This influence of spin rate on side force probably is caused by a lag in the position or strength of the vortex as the vortices switch sides. It should be noted that, for the highest spin rate of 8 Hz, the body rotates approximately 9 deg in the time a molecule of air travels the length of the body (i.e., $\omega\ell/U = 0.024$, were ω = angular velocity, ℓ = length, and U = velocity).

The effect of spin rate on side-force amplitude does not agree with that of Ref. 3, where no effect was noted. Although the exact reasons for this are not known, there are several possibilities, including the following. First, the geometries are vastly different: a blunt-nosed long slender body vs the sharp cone of the present test. Second, the multiple switching per spin cycle in the present case results in a significantly higher equivalent spin rate than that of Ref. 3. And third, different test techniques were used: constant spin rate was used in the tests reported here, and the spin-down method was used in Ref. 3.

In conclusion, tests on a spinning cone indicate that the side force observed during static testing occurs under conditions of spin about the longitudinal axis. The general shape of the side-force curve with roll position is not a strong function of spin rate. However, the peak-to-peak value of side force decreases significantly with spin rate, suggesting that the vortices that produce the side force require a significant amount of time to change position and/or strength.

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